OFFICE OF NAVAL RESEARCH

Grant N00014-90-J-1193

TECHNICAL REPORT No. 8

Reply to "Coupled s- and d-Wave States in the Thorium-Doped Heavy-Fermion Superconductor UBe_{13}" by H. Pleiner and H. R. Brand

by

D. Sahu, A. Langner and Thomas F. George

Prepared for Publication

in

Physical Review B

Departments of Chemistry and Physics
State University of New York at Buffalo
Buffalo, New York 14260

March 1990

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): UBUFFALO/DC/90/TR-8	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Depts. Chemistry & Physics, State University of New York; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Fronczak Hall, Amherst Campus, Buffalo, New York 14260	7b. ADDRESS (City, State, and ZIP Code): Chemistry Program, 800 N. Quincy Street, Arlington, Virginia 22217
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Office of Naval Research; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: Grant N00014-90-J-1193
8c. ADDRESS (City, State, and ZIP Code): Chemistry Program, 800 N. Quincy Street, Arlington, Virginia 22217	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Reply to "Coupled s- and d-Wave States in the Thorium-Doped Heavy-Fermion Superconductor UBe_{13}" by H. Pleiner and H. R. Brand

12. PERSONAL AUTHOR(S) D. Sahu, A. Langner and Thomas F. George

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM ____ TO ____	March 1990	4

16. SUPPLEMENTARY NOTATION

Prepared for publication in Physical Review B

17. COSATI CODES FIELD	GROUP	SUB-GROUP	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
			SUPERCONDUCTOR UBe_{13}	COUPLED s- AND d-WAVE STATES
			THORIUM-DOPED	THEORETICAL ANALYSIS
			HEAVY FERMION	SYMMETRY CONSIDERATIONS

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

We discuss the points raised by H. Pleiner and H. R. Brand concerning our earlier work on UBe_{13} and thorium-doped UBe_{13}.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr. David L. Nelson	22b. TELEPHONE (Include Area Code): (202) 696-4410; 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Physical Review B, in press

Reply to "Coupled s- and d-Wave States in the Thorium-Doped Heavy-Fermion Superconductor UBe_{13}" by H. Pleiner and H. R. Brand

D. Sahu, A. Langner and Thomas F. George
Departments of Physics and Chemistry
239 Fronczak Hall
State University of New York at Buffalo
Buffalo, New York 14260

Abstract

We discuss the points raised by H. Pleiner and H. R. Brand concerning our earlier work on UBe_{13} and thorium-doped UBe_{13}.

PACS Nos.: 74.70.Tx, 74.20.De

In two recent papers[1,2] we examined the question of lowest-order coupling among even-parity superconducting states utilizing general symmetry considerations as guiding principles. Our approach was motivated by the work of Kumar and Wölfle (KW),[3] whose conclusions we generalized[1] and examined more closely.[2] Our works[1,2] have been criticized by Pleiner and Brand[4] (PB) who argue that we misinterpreted KW. Our response spells out why the criticisms of PB appears to us to be without foundation.

PB claim[4] that KW followed a two-step procedure for minimizing their free energy in Ref. 3: first KW minimized their free energy with respect to Δ_1 (the order parameter for $d_{x^2-y^2}$-state) and concluded that this must be zero for stability reasons. This enabled KW, in a second step, to write down their free energy involving Δ_2 (the order parameter for the axial $d_{2z^2-x^2-y^2}$-state) and Δ_0 (the order parameter for the isotropic s-state). Since this two-step procedure is never mentioned by KW in writing Eq. 1 of Ref. 3, the question of misinterpreting KW on this point does not arise.

In addition, we would like to comment on the claim of PB that a non-zero Δ_1 can never be an equilibrium state. Our detailed numerical work[2] suggests otherwise. We find that a transition from an s-wave state (state IV of Ref. 2) to a mixed state with both d-wave components of the two-dimensional representation non-zero (state VII of Ref. 2) is clearly favored over that of a transition to a mixed state with $\Delta_1 = 0$, $\Delta_2 \neq 0$ and $\Delta_0 \neq 0$ (state VI of Ref. 2). To account for the specific heat data, one clearly needs a non-zero Δ_1, as has been realized by KW[5] and by us.[6]

We are well aware of the required symmetry breaking to achieve second-order transitions to the various superconducting states. This point has been well addressed in Ref. 7. However, as is also mentioned in Ref. 7, the

symmetry breaking is to a lower symmetry subgroup of the cubic group. Our analysis incorporates this progression. It should be noted that PB do not substantiate their claims by any detailed calculations as we have done in Ref. 2; they merely state in general terms that in the symmetry-broken phase "a given state can have lower symmetry than the crystal symmetry." The question as to whether state VI of Ref. 2 is stable or unstable with respect to the introduction of a Δ_1 perturbation is left unanswered by PB. Furthermore, their earlier work in Ref. 8, being based on the unsubstantiated points of Ref. 4, seems to us to be questionable.

This research was supported by the Office of Naval Research and by an award from the New York State Institute on Superconductivity in conjunction with the New York State Energy Research and Development Authority.

1. D. Sahu, A. Langner and T. F. George, Phys. Rev. B 38, 2466 (1988).
2. A. Langner, D. Sahu and T. F. George, Phys. Rev. B 38, 9187 (1988).
3. P. Kumar and P. Wölfle, Phys. Rev. Lett. 59, 1954 (1987).
4. H. Pleiner and H. R. Brand, preceeding Comment.
5. P. Kumar (private communication).
6. D. Sahu, A. Langner and T. F. George (unpublished)
7. I. A. Luk'yanchuk and V. P. Mineev, Pis'ma Zh.Eksp. Teor. Fiz. 47, 460 (1988) (JETP Lett. 47, 543 (1988)).
8. H. R. Brand, M. M. Doria and H. Pleiner, Phys. Rev. Lett. (Comment) 60, 2810 (1988).

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	No. Copies
Office of Naval Research Attn: Code 1113 800 N. Quincy Street Arlington, Virginia 22217-5000	2
Dr. Bernard Douda Naval Weapons Support Center Code 50C Crane, Indiana 47522-5050	1
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko, Code L52 Port Hueneme, California 93401	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12 high quality
DTNSRDC Attn: Dr. H. Singerman Applied Chemistry Division Annapolis, Maryland 21401	1
Dr. William Tolles Superintendent Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375-5000	1

	No. Copies
Dr. David Young Code 334 NORDA NSTL, Mississippi 39529	1
Naval Weapons Center Attn: Dr. Ron Atkins Chemistry Division China Lake, California 93555	1
Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	1
U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709	1
Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1
Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1
Dr. David L. Nelson Chemistry Division Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217	1

ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. J. E. Jensen
Hughes Research Laboratory
3011 Malibu Canyon Road
Malibu, California 90265

Dr. J. H. Weaver
Department of Chemical Engineering
and Materials Science
University of Minnesota
Minneapolis, Minnesota 55455

Dr. A. Reisman
Microelectronics Center of North Carolina
Research Triangle Park, North Carolina
27709

Dr. M. Grunze
Laboratory for Surface Science and
Technology
University of Maine
Orono, Maine 04469

Dr. J. Butler
Naval Research Laboratory
Code 6115
Washington D.C. 20375-5000

Dr. L. Interante
Chemistry Department
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. Irvin Heard
Chemistry and Physics Department
Lincoln University
Lincoln University, Pennsylvania 19352

Dr. K.J. Klaubunde
Department of Chemistry
Kansas State University
Manhattan, Kansas 66506

Dr. C. B. Harris
Department of Chemistry
University of California
Berkeley, California 94720

Dr. F. Kutzler
Department of Chemistry
Box 5055
Tennessee Technological University
Cookesville, Tennessee 38501

Dr. D. DiLella
Chemistry Department
George Washington University
Washington D.C. 20052

Dr. R. Reeves
Chemistry Department
Renssaeler Polytechnic Institute
Troy, New York 12181

Dr. Steven M. George
Stanford University
Department of Chemistry
Stanford, CA 94305

Dr. Mark Johnson
Yale University
Department of Chemistry
New Haven, CT 06511-8118

Dr. W. Knauer
Hughes Research Laboratory
3011 Malibu Canyon Road
Malibu, California 90265

ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. G. A. Somorjai
Department of Chemistry
University of California
Berkeley, California 94720

Dr. J. Murday
Naval Research Laboratory
Code 6170
Washington, D.C. 20375-5000

Dr. J. B. Hudson
Materials Division
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. Theodore E. Madey
Surface Chemistry Section
Department of Commerce
National Bureau of Standards
Washington, D.C. 20234

Dr. J. E. Demuth
IBM Corporation
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, New York 10598

Dr. M. G. Lagally
Department of Metallurgical
and Mining Engineering
University of Wisconsin
Madison, Wisconsin 53706

Dr. R. P. Van Duyne
Chemistry Department
Northwestern University
Evanston, Illinois 60637

Dr. J. M. White
Department of Chemistry
University of Texas
Austin, Texas 78712

Dr. D. E. Harrison
Department of Physics
Naval Postgraduate School
Monterey, California 93940

Dr. R. L. Park
Director, Center of Materials
Research
University of Maryland
College Park, Maryland 20742

Dr. W. T. Peria
Electrical Engineering Department
University of Minnesota
Minneapolis, Minnesota 55455

Dr. Keith H. Johnson
Department of Metallurgy and
Materials Science
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dr. S. Sibener
Department of Chemistry
James Franck Institute
5640 Ellis Avenue
Chicago, Illinois 60637

Dr. Arnold Green
Quantum Surface Dynamics Branch
Code 3817
Naval Weapons Center
China Lake, California 93555

Dr. A. Wold
Department of Chemistry
Brown University
Providence, Rhode Island 02912

Dr. S. L. Bernasek
Department of Chemistry
Princeton University
Princeton, New Jersey 08544

Dr. W. Kohn
Department of Physics
University of California, San Diego
La Jolla, California 92037

ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. F. Carter
Code 6170
Naval Research Laboratory
Washington, D.C. 20375-5000

Dr. Richard Colton
Code 6170
Naval Research Laboratory
Washington, D.C. 20375-5000

Dr. Dan Pierce
National Bureau of Standards
Optical Physics Division
Washington, D.C. 20234

Dr. R. Stanley Williams
Department of Chemistry
University of California
Los Angeles, California 90024

Dr. R. P. Messmer
Materials Characterization Lab.
General Electric Company
Schenectady, New York 22217

Dr. Robert Gomer
Department of Chemistry
James Franck Institute
5640 Ellis Avenue
Chicago, Illinois 60637

Dr. Ronald Lee
R301
Naval Surface Weapons Center
White Oak
Silver Spring, Maryland 20910

Dr. Paul Schoen
Code 6190
Naval Research Laboratory
Washington, D.C. 20375-5000

Dr. John T. Yates
Department of Chemistry
University of Pittsburgh
Pittsburgh, Pennsylvania 15260

Dr. Richard Greene
Code 5230
Naval Research Laboratory
Washington, D.C. 20375-5000

Dr. L. Kesmodel
Department of Physics
Indiana University
Bloomington, Indiana 47403

Dr. K. C. Janda
University of Pittsburg
Chemistry Building
Pittsburg, PA 15260

Dr. E. A. Irene
Department of Chemistry
University of North Carolina
Chapel Hill, North Carolina 27514

Dr. Adam Heller
Bell Laboratories
Murray Hill, New Jersey 07974

Dr. Martin Fleischmann
Department of Chemistry
University of Southampton
Southampton 509 5NH
UNITED KINGDOM

Dr. H. Tachikawa
Chemistry Department
Jackson State University
Jackson, Mississippi 39217

Dr. John W. Wilkins
Cornell University
Laboratory of Atomic and
Solid State Physics
Ithaca, New York 14853

ABSTRACTS DISTRIBUTION LIST, 056/625/629

Dr. R. G. Wallis
Department of Physics
University of California
Irvine, California 92664

Dr. D. Ramaker
Chemistry Department
George Washington University
Washington, D.C. 20052

Dr. J. C. Hemminger
Chemistry Department
University of California
Irvine, California 92717

Dr. T. F. George
Chemistry Department
University of Rochester
Rochester, New York 14627

Dr. G. Rubloff
IBM
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, New York 10598

Dr. Horia Metiu
Chemistry Department
University of California
Santa Barbara, California 93106

Dr. W. Goddard
Department of Chemistry and Chemical Engineering
California Institute of Technology
Pasadena, California 91125

Dr. P. Hansma
Department of Physics
University of California
Santa Barbara, California 93106

Dr. J. Baldeschwieler
Department of Chemistry and Chemical Engineering
California Institute of Technology
Pasadena, California 91125

Dr. J. T. Keiser
Department of Chemistry
University of Richmond
Richmond, Virginia 23173

Dr. R. W. Plummer
Department of Physics
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Dr. E. Yeager
Department of Chemistry
Case Western Reserve University
Cleveland, Ohio 41106

Dr. N. Winograd
Department of Chemistry
Pennsylvania State University
University Park, Pennsylvania 16802

Dr. Roald Hoffmann
Department of Chemistry
Cornell University
Ithaca, New York 14853

Dr. A. Steckl
Department of Electrical and Systems Engineering
Rensselaer Polytechnic Institute
Troy, NewYork 12181

Dr. G.H. Morrison
Department of Chemistry
Cornell University
Ithaca, New York 14853